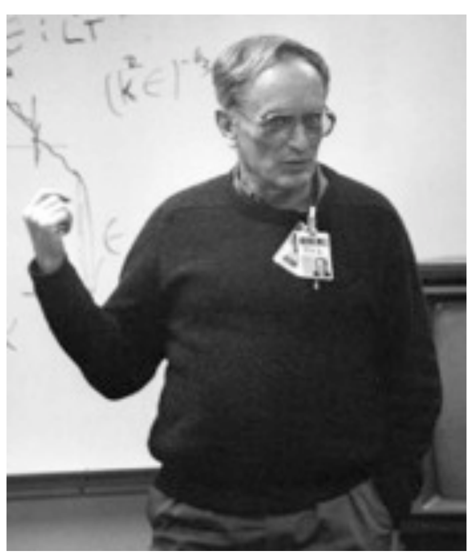

The Ongoing Revolution
In Global Modeling

Ancestral Models

- The GFDL model
  - First cumulus parameterization
  - “Bucket” model for the land surface
  - Relatively high vertical resolution
- The UCLA model
  - Conservative numerical methods
  - Mass-flux convection
  - First predicted clouds
- The Livermore model
  - Pressure as the vertical coordinate
  - Unrealistically strong horizontal smoothing
  - Short lifetime
- The NCAR model
  - Height as the vertical coordinate
  - Water vapor not predicted

The 1960s



Global modeling in the 60s

- Purely academic
- Modest funding
- Finite differences everywhere
- First coupled ocean-atmosphere model
- Early studies of predictability
- First work on data assimilation

Global modeling in the 70s

- More global modeling centers are set up
- First simulations of annual cycles
- Global NWP begins
- Vector computing
- More simulations of global warming
- "Climate simulation" usually means a perpetual January with prescribed SSTs
- Cloud feedbacks are identified as a key issue
- Satellite data increases in importance for both NWP and climate model evaluation

Global Modeling in the 80s

Hilding Sundqvist argues for predicting cloud water and ice.

Coupled ocean-atmosphere models become more mature.

The CCM is born.

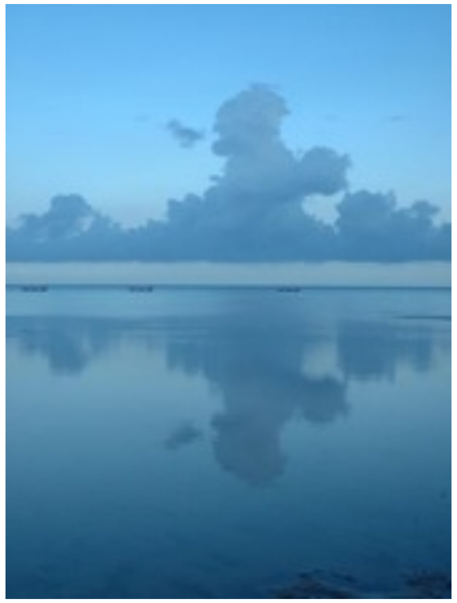
Global warming enters the public consciousness.

Land-surface modeling gets a higher profile.

The spectral method becomes popular.

ERBE is launched, and the ERB gets lots of attention.

True climate simulation begins.



Global modeling in the 90s

- The Age of Intercomparison begins
- Reanalysis gets under way
- Semi-Lagrangian advection becomes popular
- Parameterization testing becomes organized
- The carbon cycle gets attention
- Aerosols become widely appreciated
- The IPCC begins its work
- Operational seasonal prediction with coupled models begins
- Global modeling goes corporate

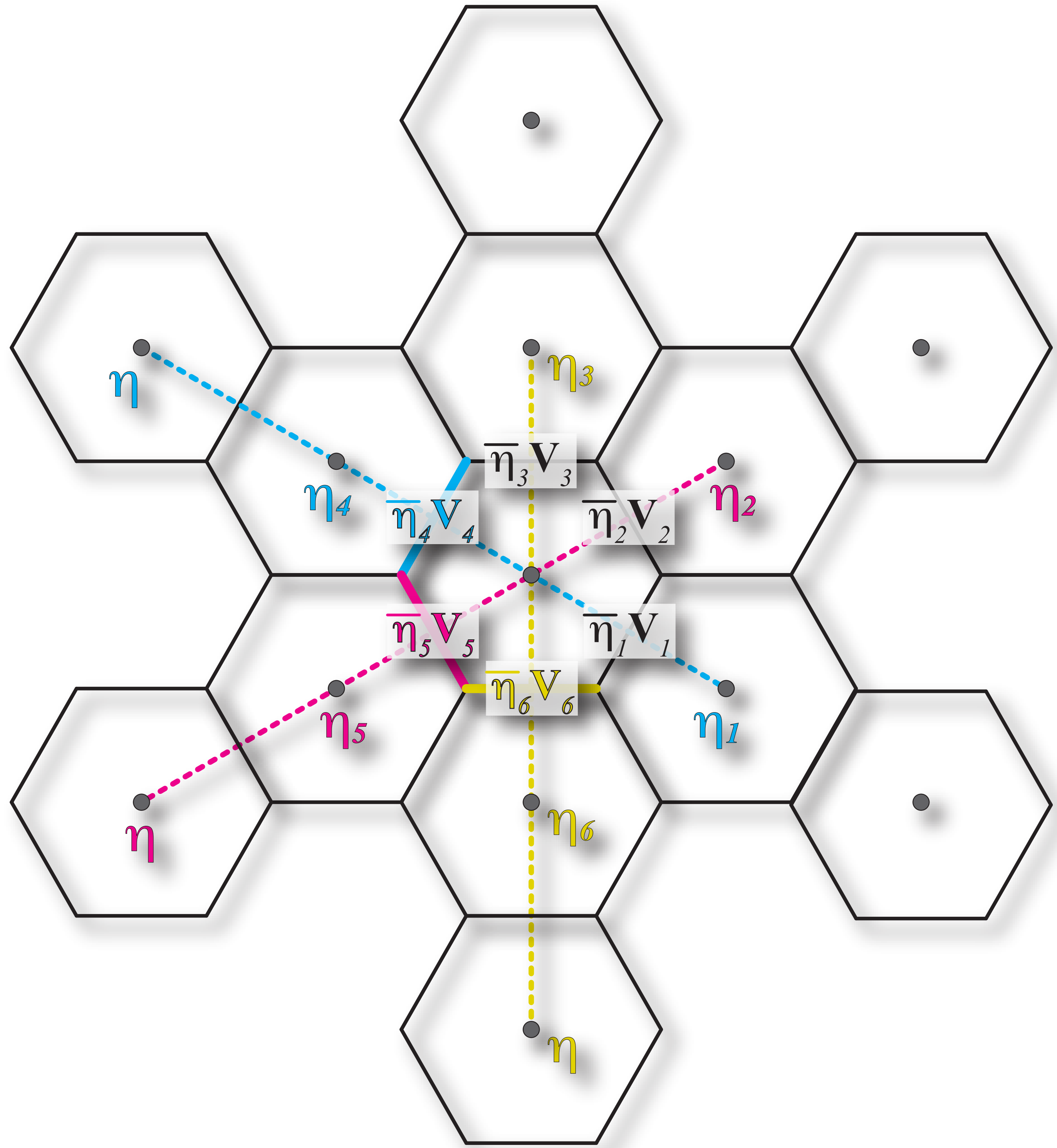
Global modeling in the 00s

- Massively parallel computing
- Very-high-resolution global models
- Carbon feedbacks
- Ice sheets

The role of computing power

- We have been getting 100 x every 10 years, forever.
- Computing power has recently crossed a threshold.
- Processor speed is now limited by energy consumption.
- Performance is now increasing through more processors:
  - OK for larger ensembles with fixed resolution & run time.
  - OK for more resolution with fixed run time & ensemble size.
  - Not OK for longer runs with fixed resolution, e.g., ice ages.

The models are complicated.



Types of Complexity

- Conceptual Complexity
  - Understanding the model
  - Maintaining the code
- Coupling Complexity
  - Broad variety of components
  - Coupling of components per se
  - Realism limited by weakest component
- Numerical Complexity
  - Number of numbers
  - Analysis and visualization

Very high-resolution models are conceptually simpler, even though they are numerically more complicated.

Parameterizations Increase Conceptual Complexity

The fundamental principles of fluid dynamics, radiative transfer, etc., are relatively simple. They apply locally, at a point.

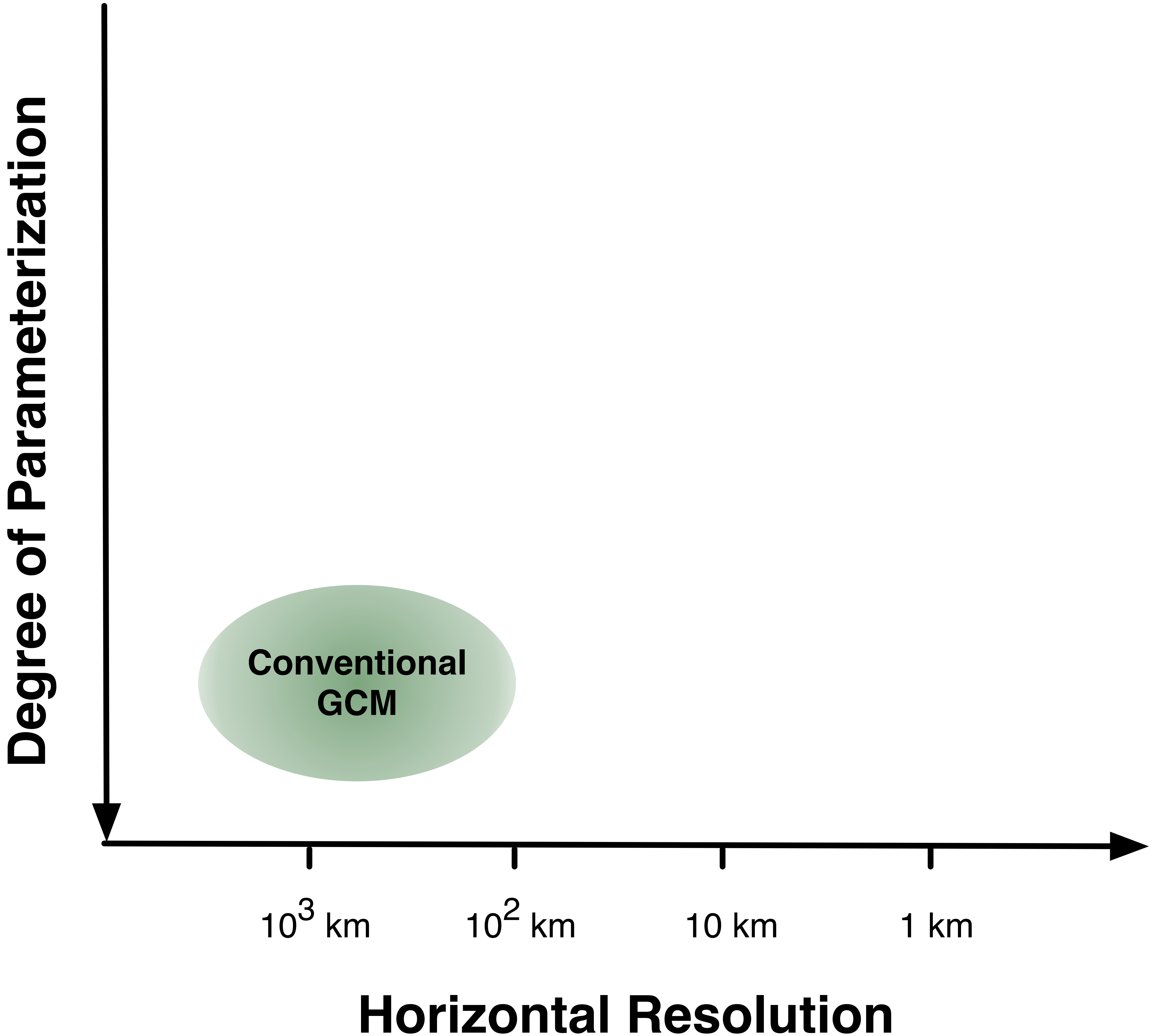
Because of limited computer resources, AGCMs are formulated to describe averages over finite volumes -- not at points.

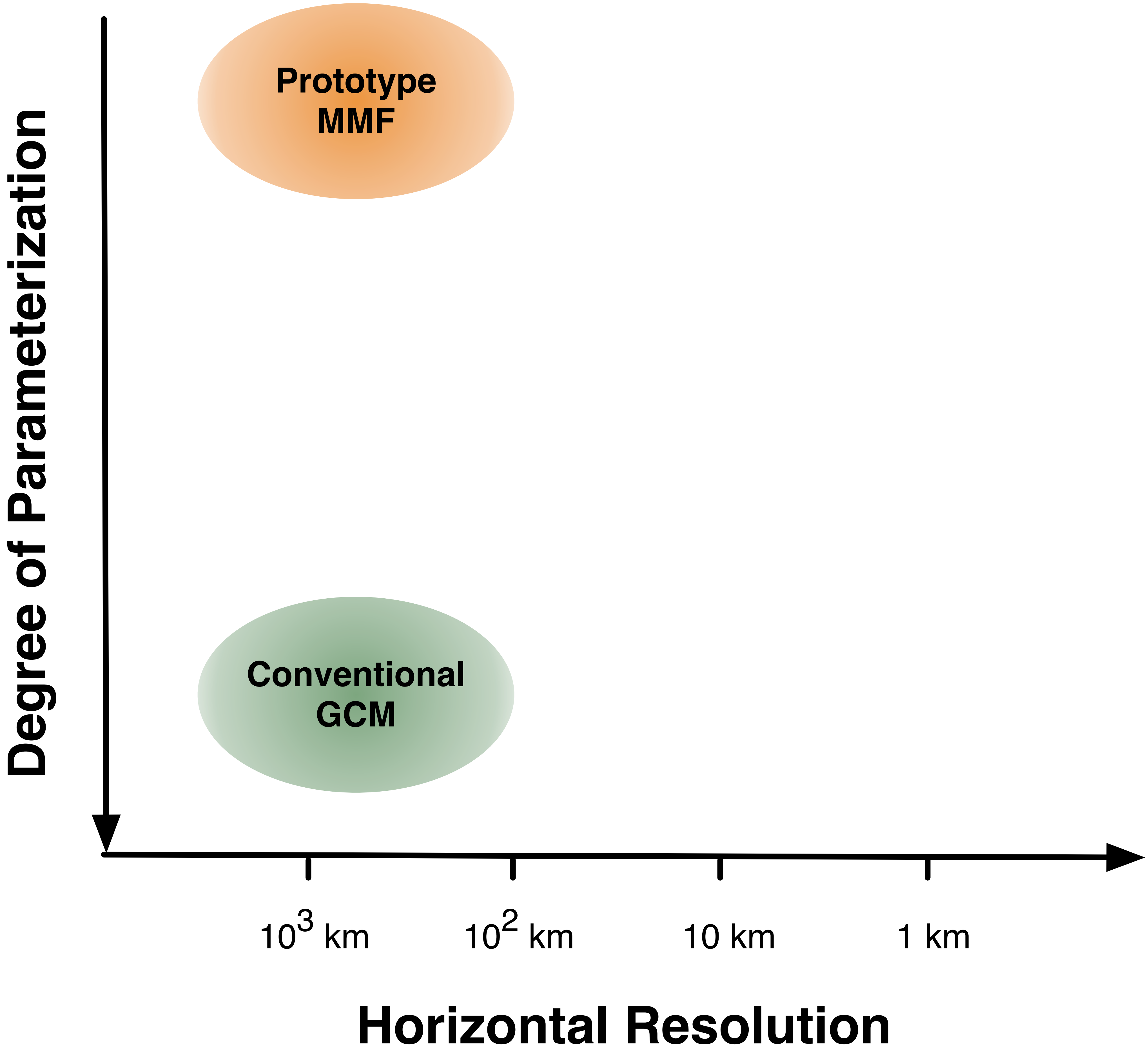
Because of nonlinearity, averaging introduces new unknowns, which are essentially statistics characterizing relevant aspects of the unresolved processes.

The fundamental principles cannot be directly applied to determine such statistics, except by going to higher spatial resolution.

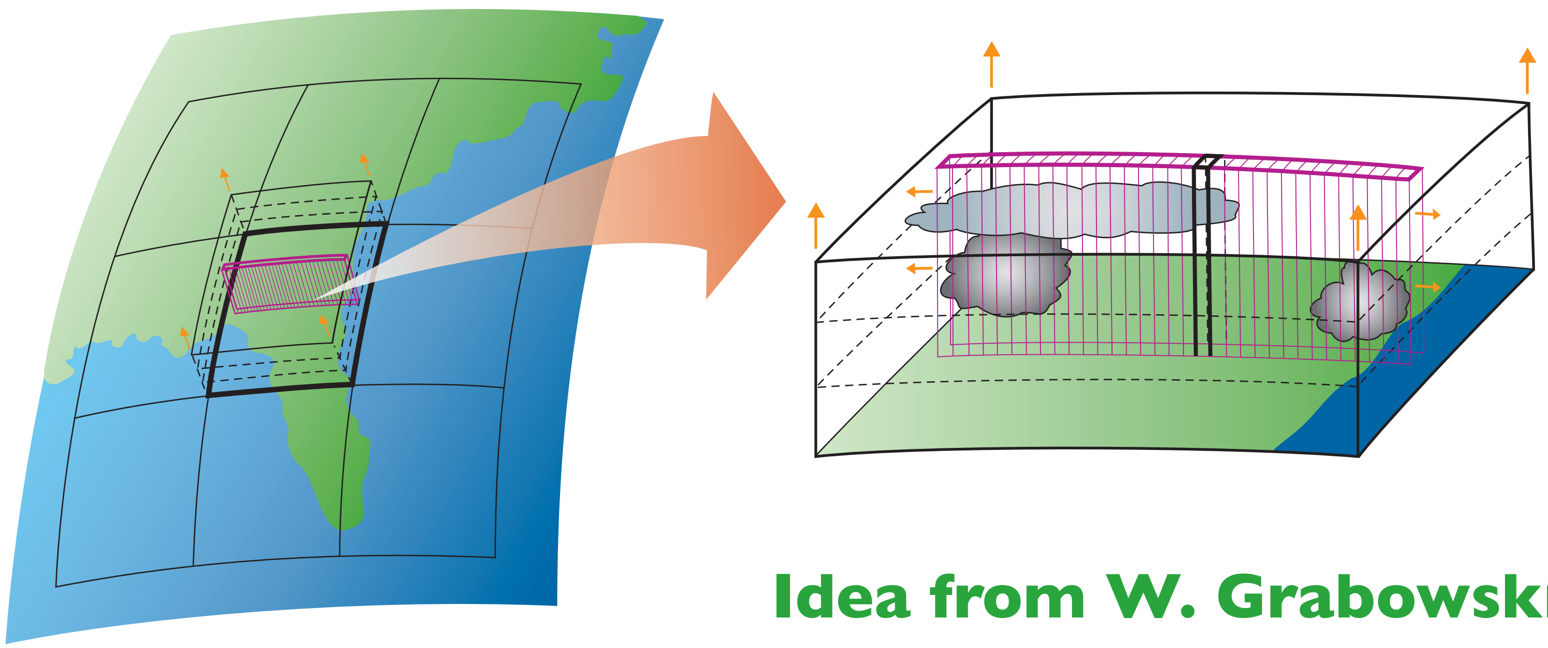
Statistical theories, called parameterizations, are used instead.

The need to predict statistics over (large) finite volumes is a major and fundamental source of conceptual complexity.


Degree of Parameterization
Conventional
GCM
10^3 km
10^2 km
10 km
1 km
Horizontal Resolution


Prototype MMF
Conventional GCM
Degree of Parameterization
10^3 km
10^2 km
10 km
1 km
Horizontal Resolution

The Multiscale Modeling Framework

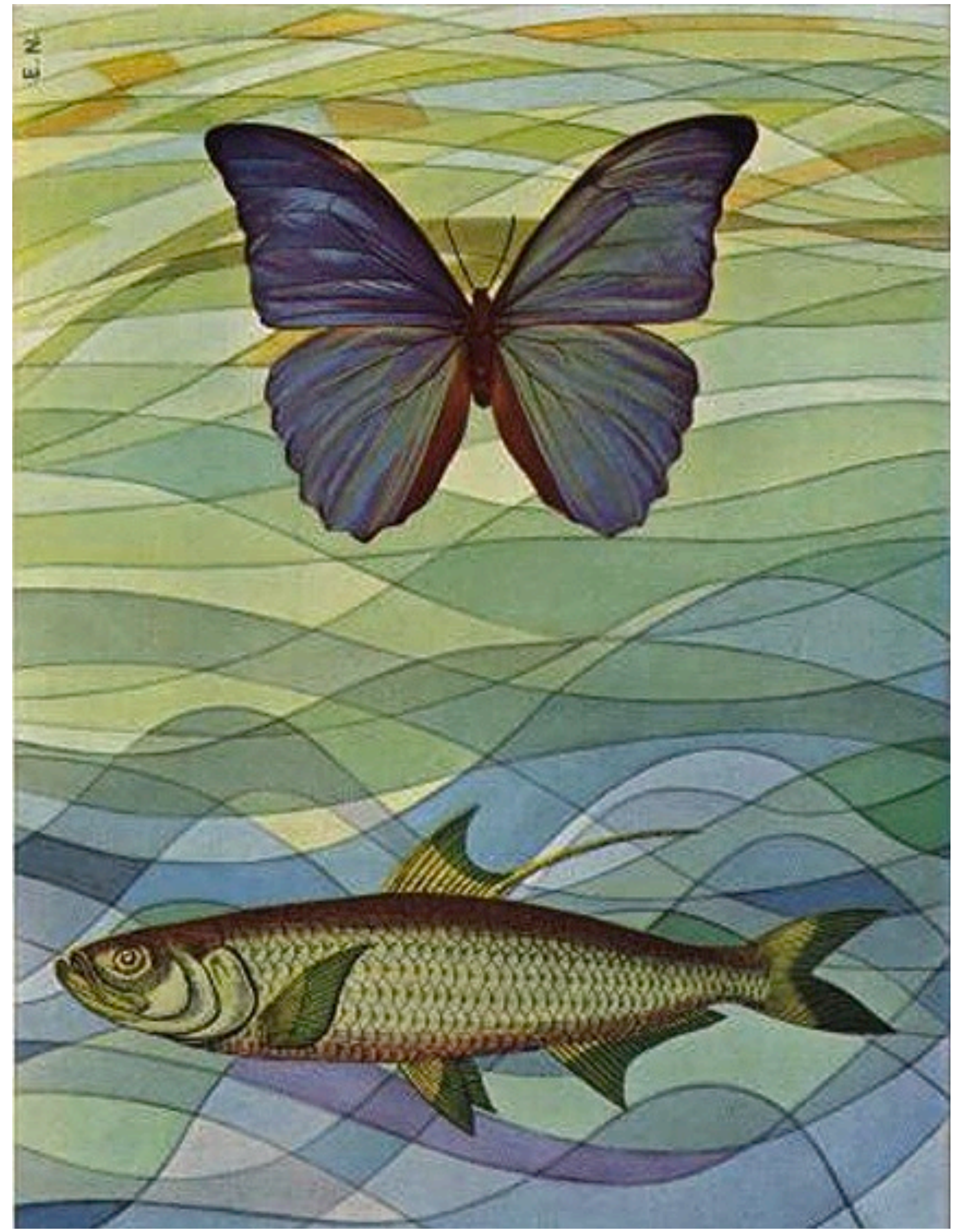


Periodic boundary conditions

Idea from W. Grabowski

A Coupled Simulation

A team led by Cristiana Stan of COLA has recently performed a coupled ocean-atmosphere simulation with the MMF.

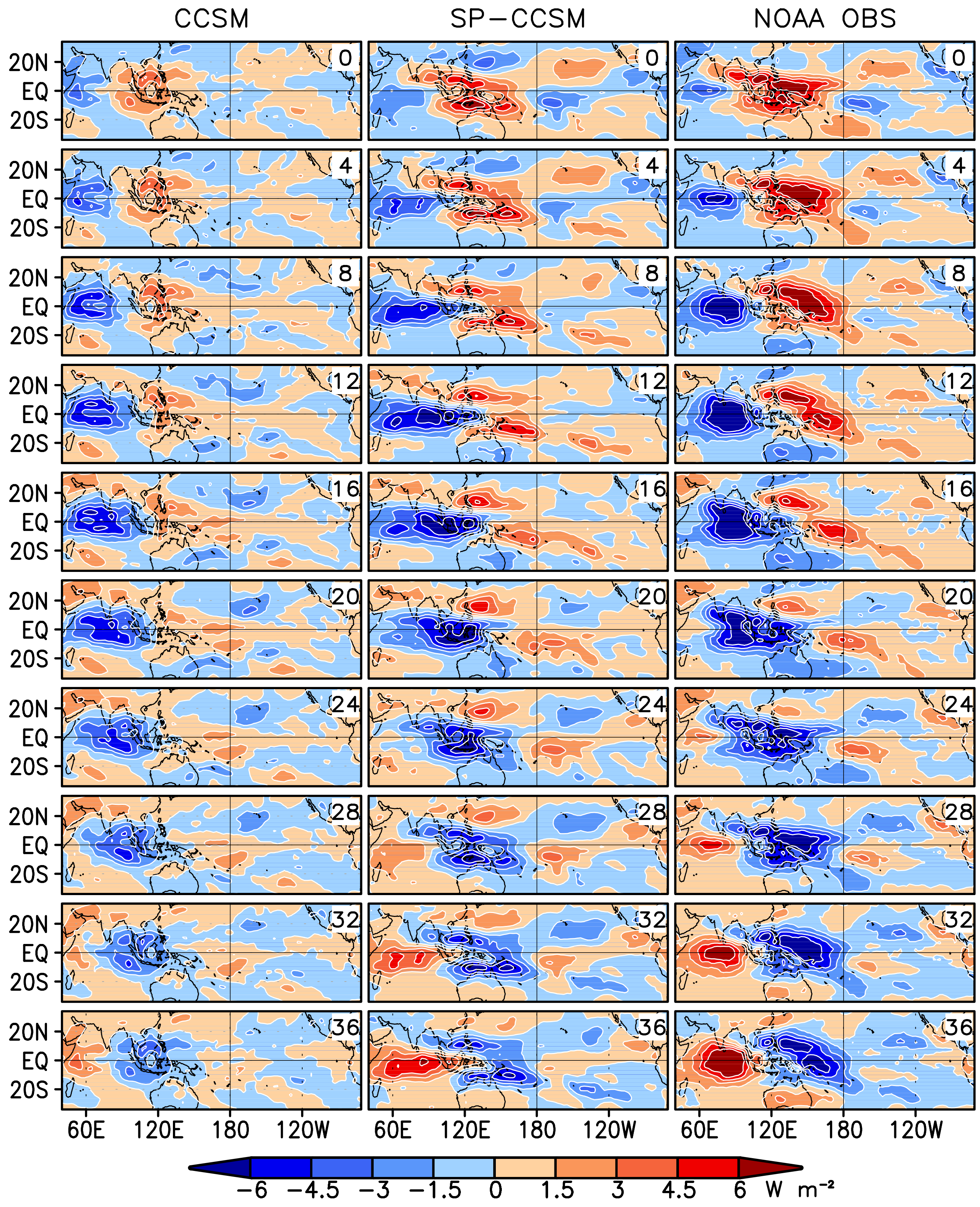


POP:

gx5v5 (3.6 deg), 25 levels, CSIM4

The MMF was not tuned in any way.

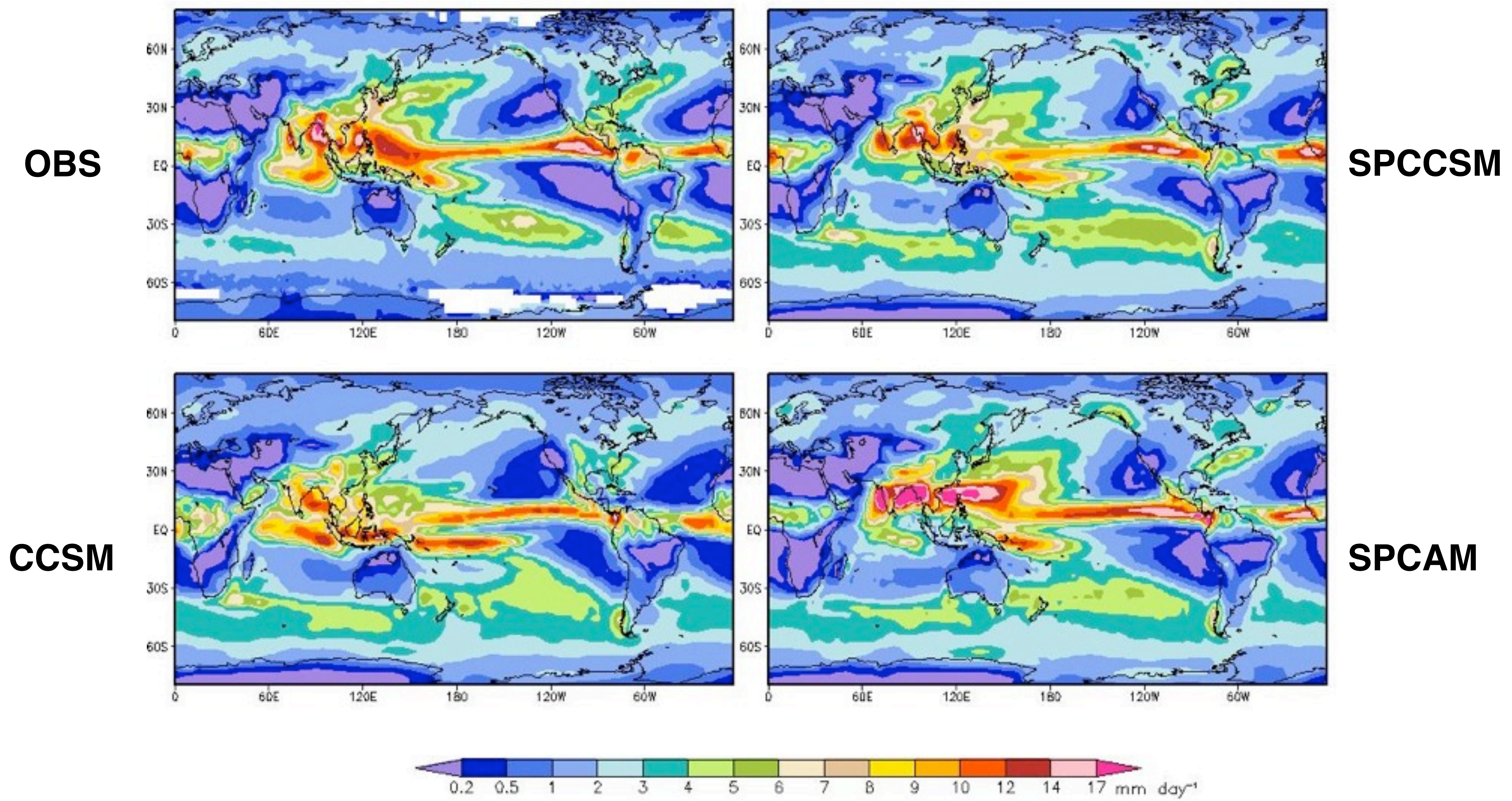
Old News

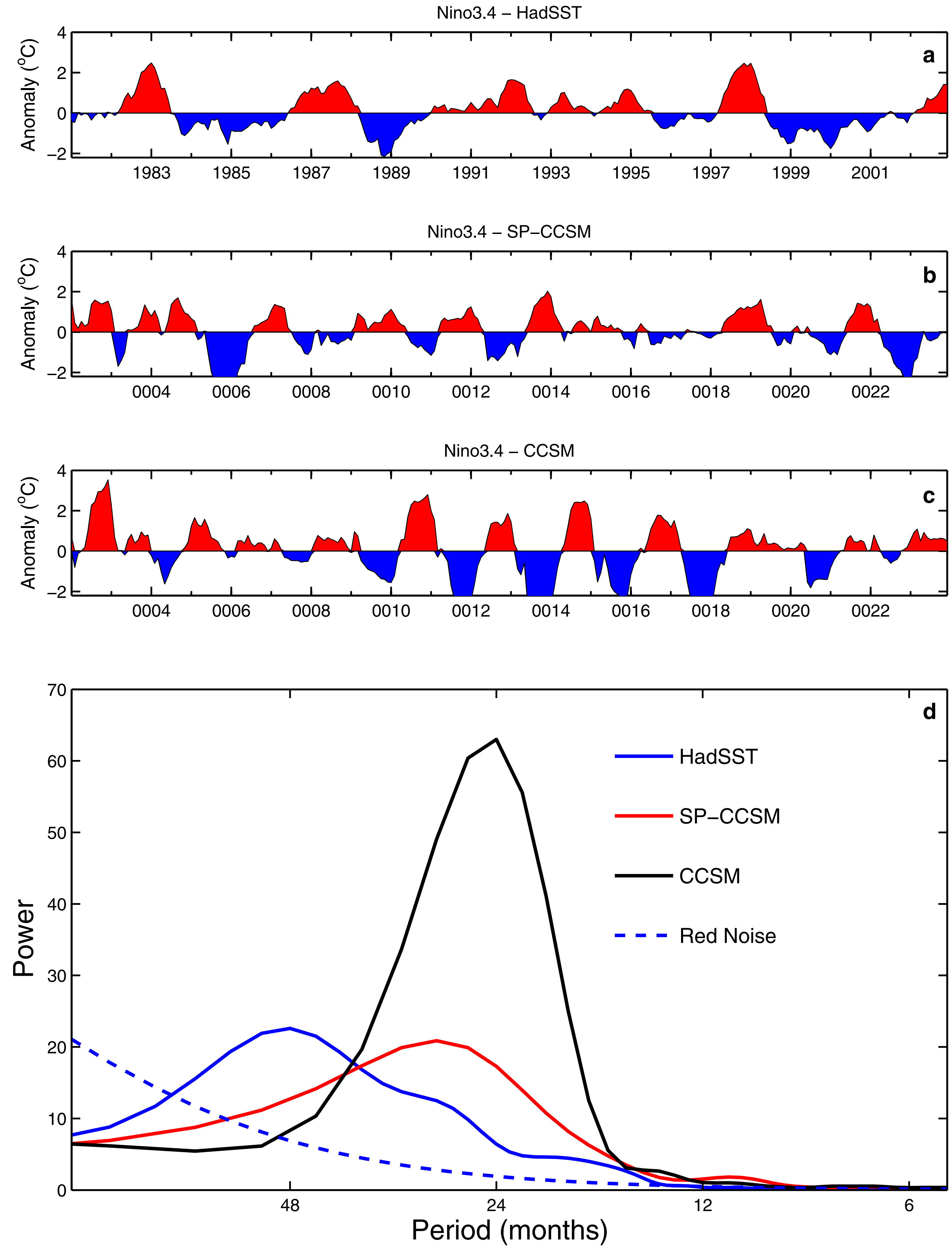


CCSM
SP−CCSM
NOAA OBS
0
4
8
12
16
20
24
28
32
36
20N
EQ
20S
60E
120E
180
120W
−6
−4.5
−3
−1.5
0
1.5
3
4.5
6
W m⁻²

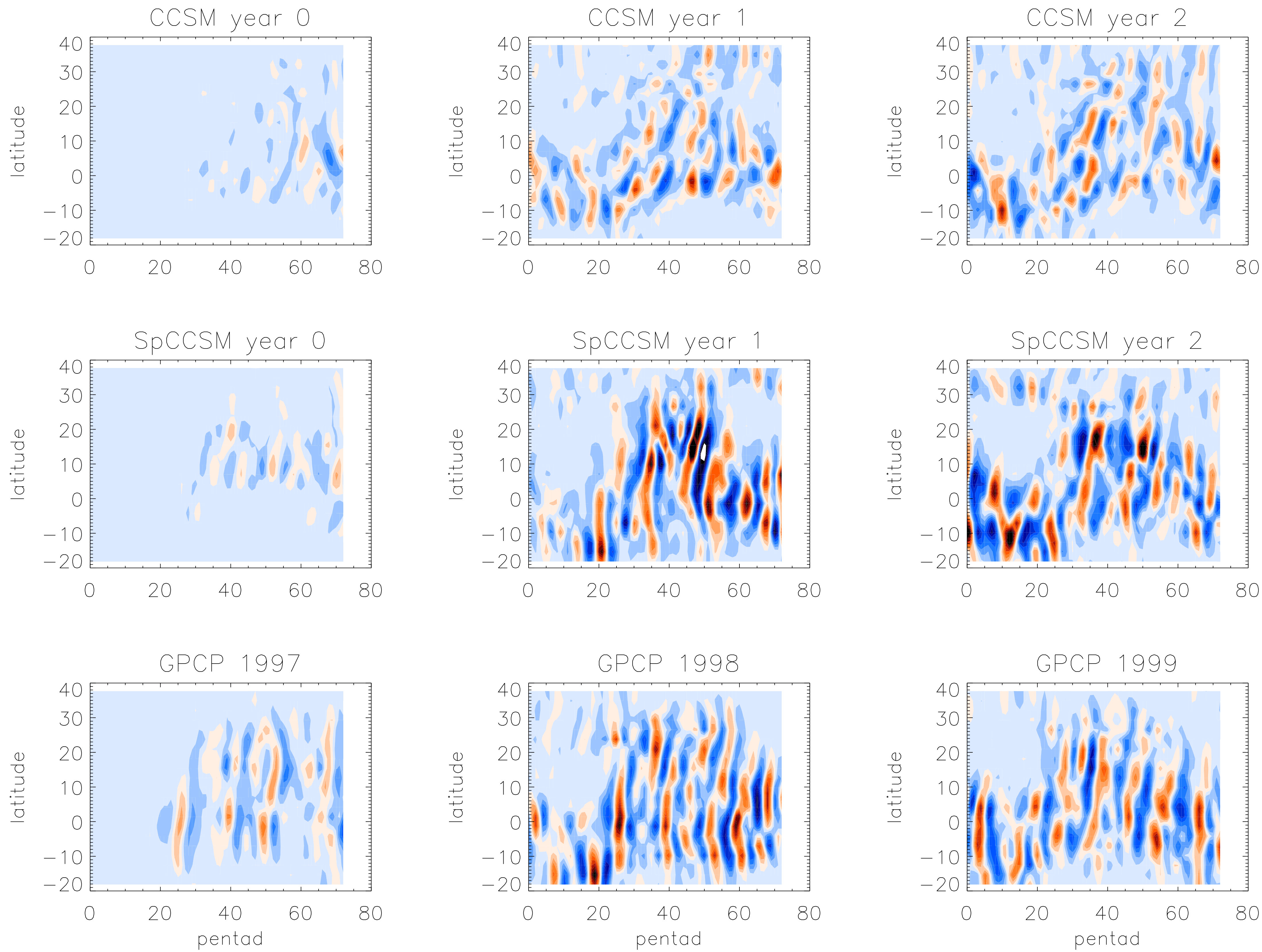
New News

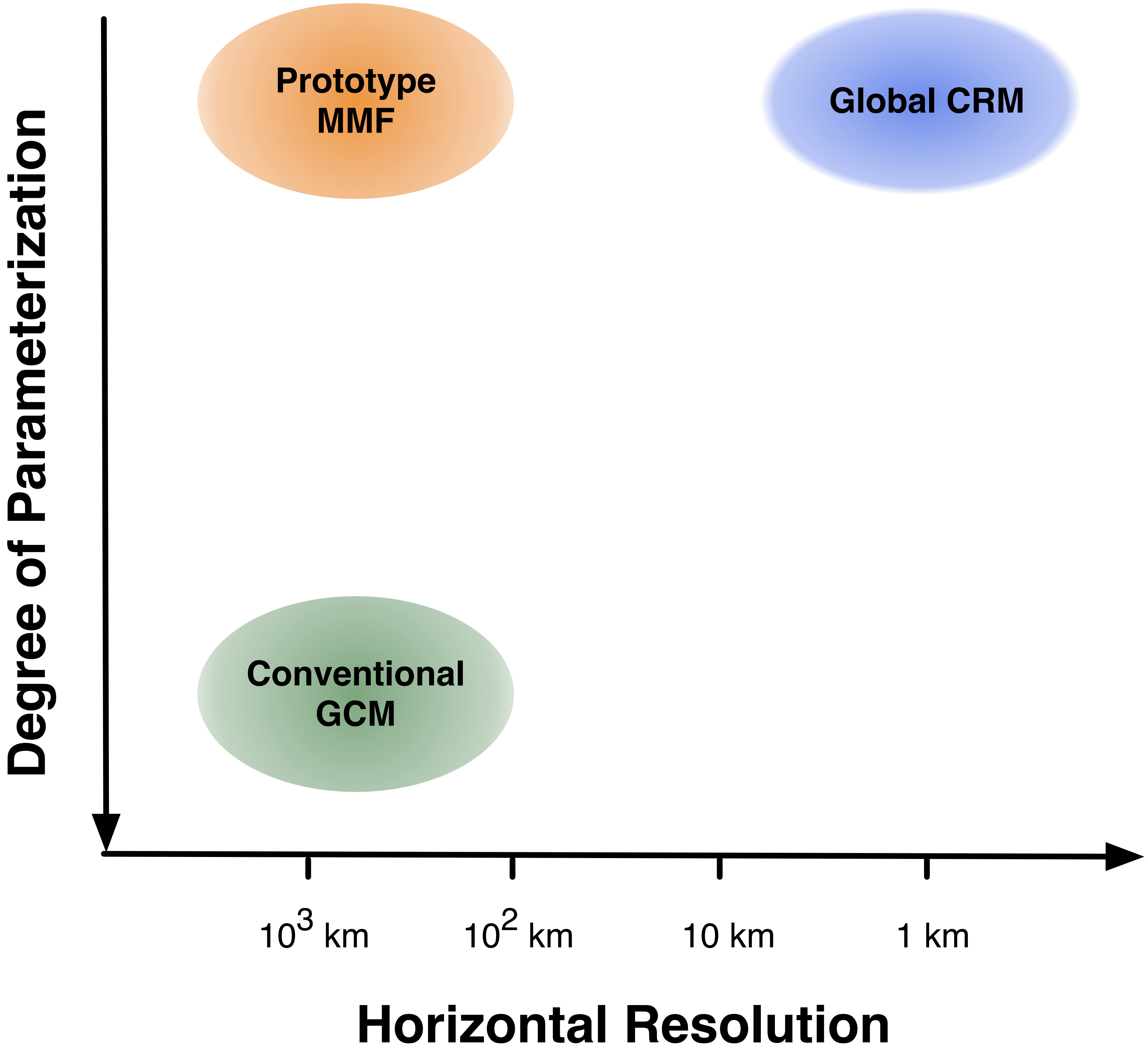
Precipitation Rate
JJA Climatology



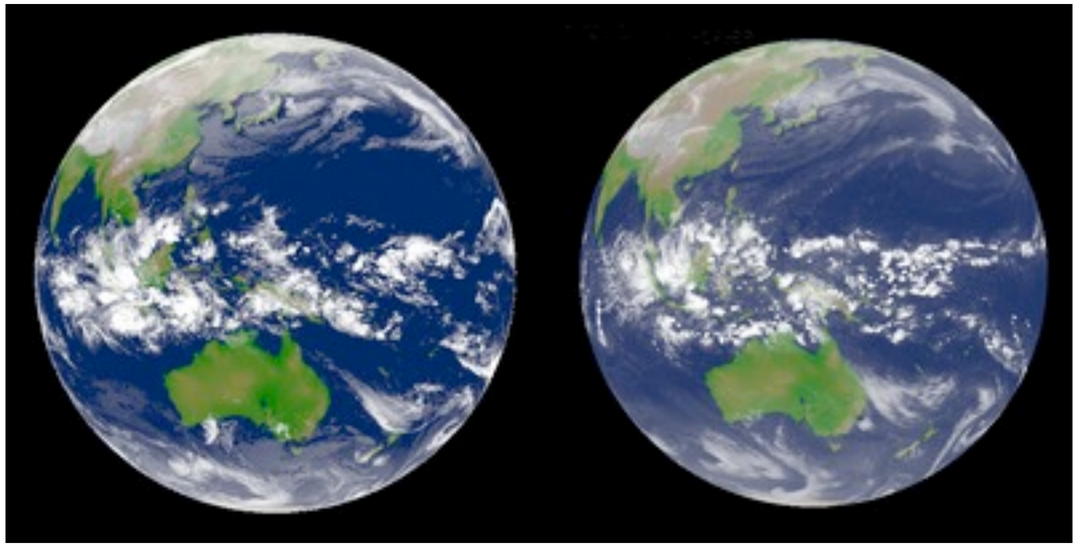

Nino3.4 – HadSST
Anomaly (°C)
a
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
Nino3.4 – SP−CCSM
b
0004
0006
0008
0010
0012
0014
0016
0018
0020
0022
Nino3.4 – CCSM
c
d
HadSST
SP−CCSM
CCSM
Red Noise
Power
48
24
12
6
Period (months)

Monsoon Precipitation




Prototype MMF
Global CRM
Conventional GCM
Degree of Parameterization
10^3 km
10^2 km
10 km
1 km
Horizontal Resolution

Global Cloud-Resolving Models



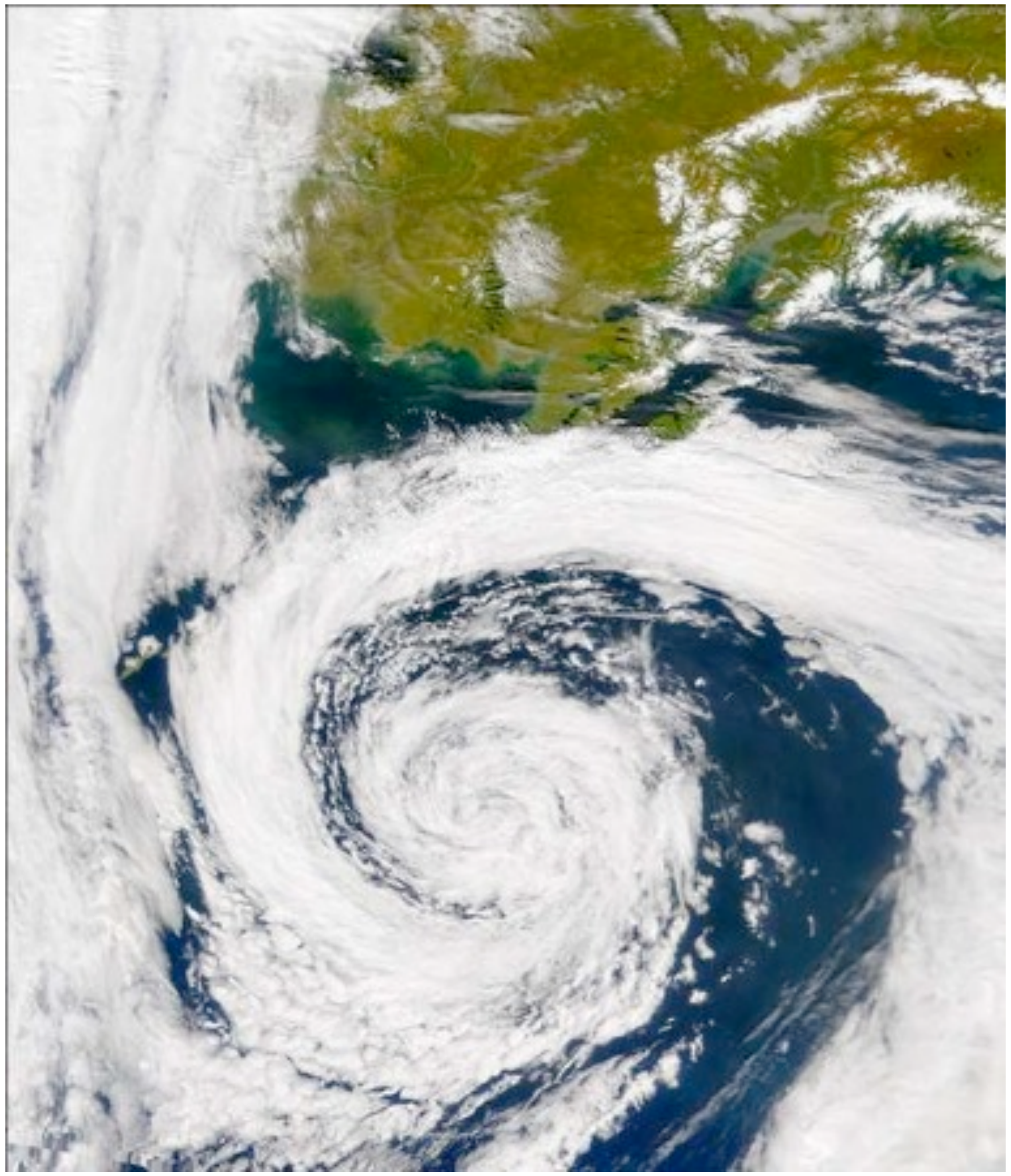
NICAM

- ~10^9 grid cells
- ~10-second time step
- ~10 simulated days per day on a 2010 computer

Building a better GCRM

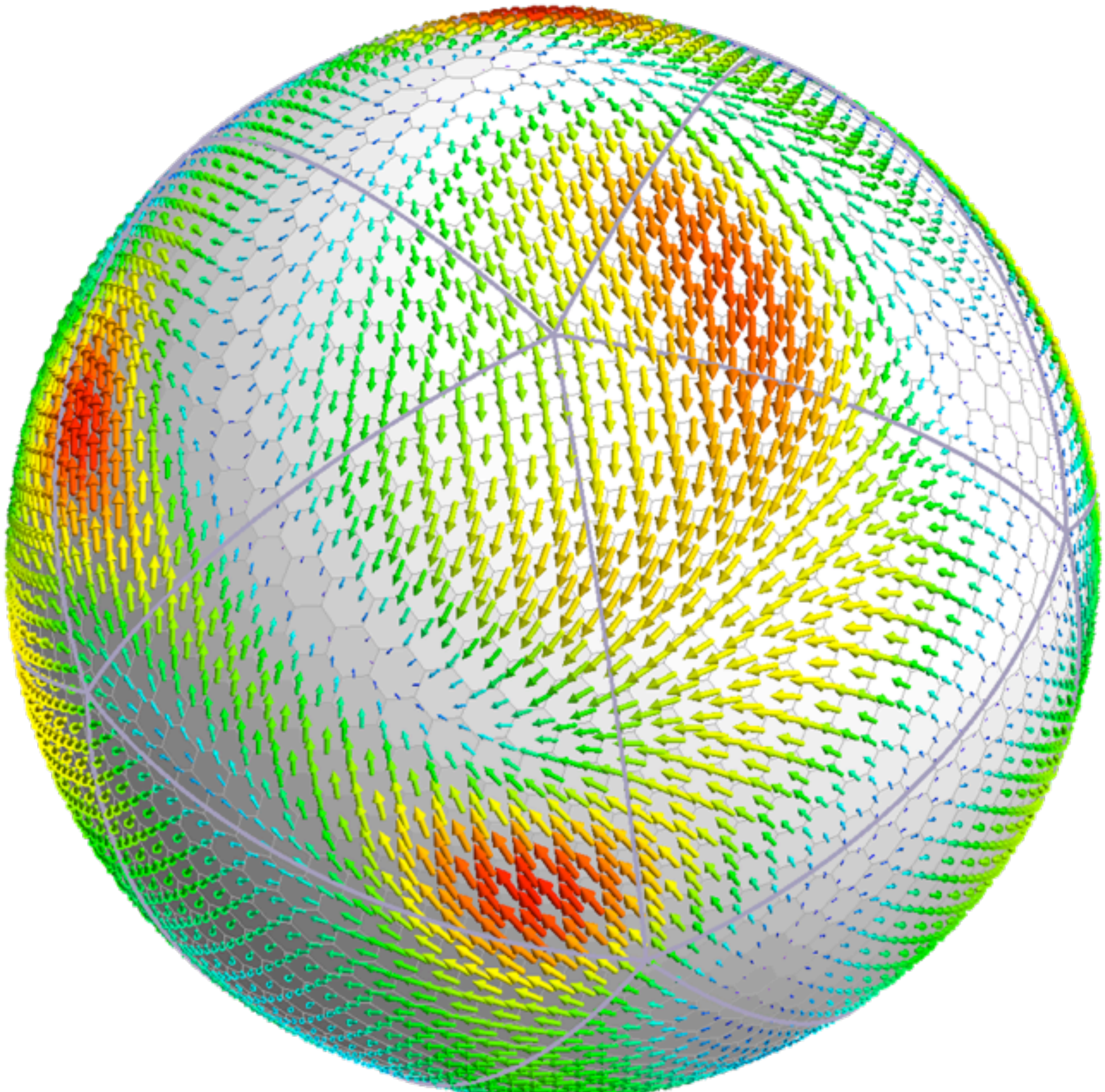
- Unified system -- filters vertically propagating sound waves, and allows a longer time step
- Vector vorticity equation -- the core of fluid dynamics
- Geodesic grid -- homogeneous, isotropic goodness

Vorticity across scales



Two New GCRMs

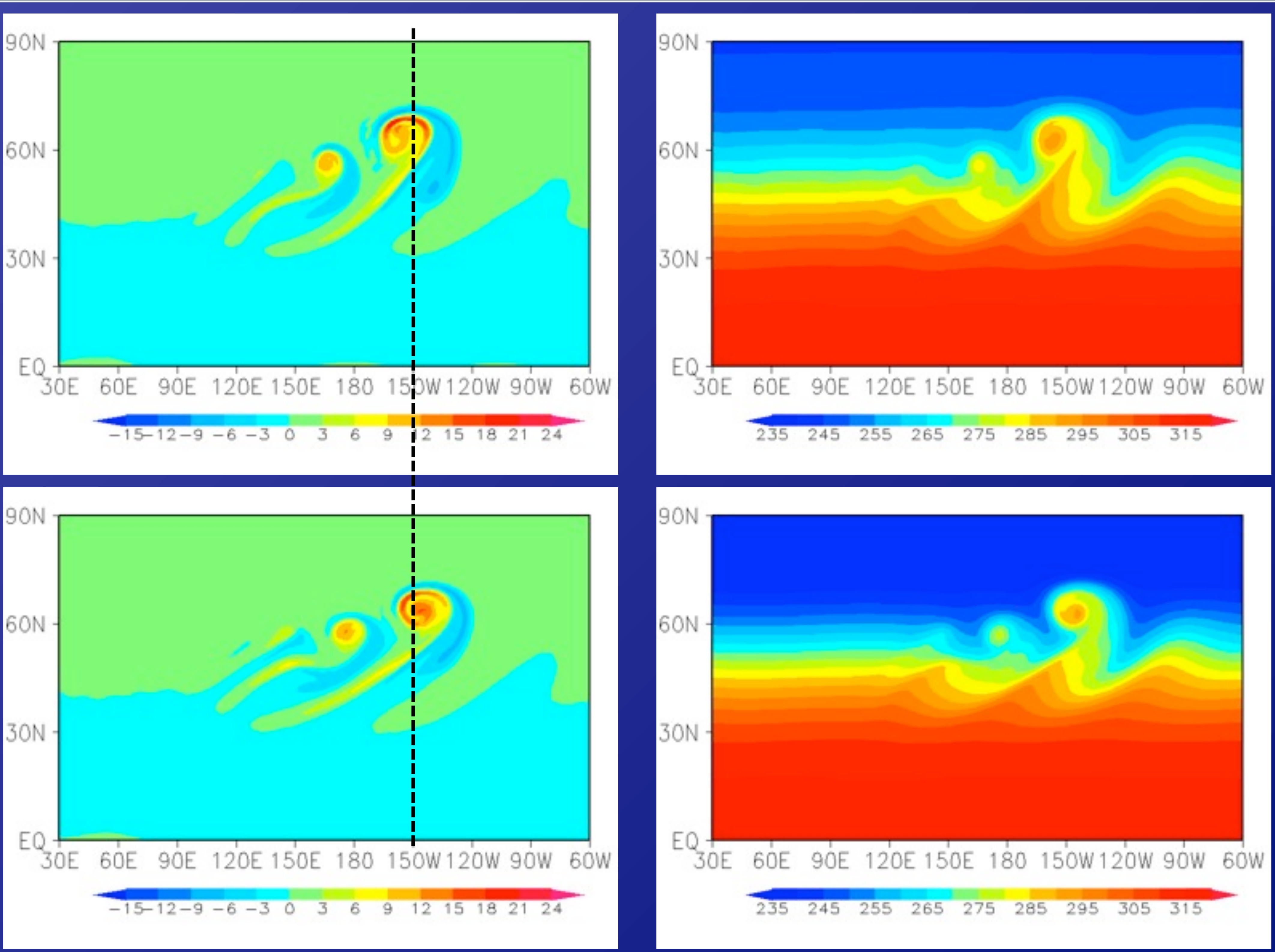
Red Team GCRM	Blue Team GCRM
Unified System	Same
Geodesic grid	Same
Charney-Phillips vertical staggering	Same
Multigrid Solver	Same (but used differently)
Predict vertical component of vorticity, and divergence of horizontal wind	Predict horizontal vorticity vector
Z grid horizontal staggering	C grid horizontal staggering
No computational modes	Computational mode in wind (filtered in tendency terms)



Testing the dynamical cores...

Unified

Anelastic



A cyclone propagates faster and potential temperature advection is weaker in the aneastic system than in the unified system.

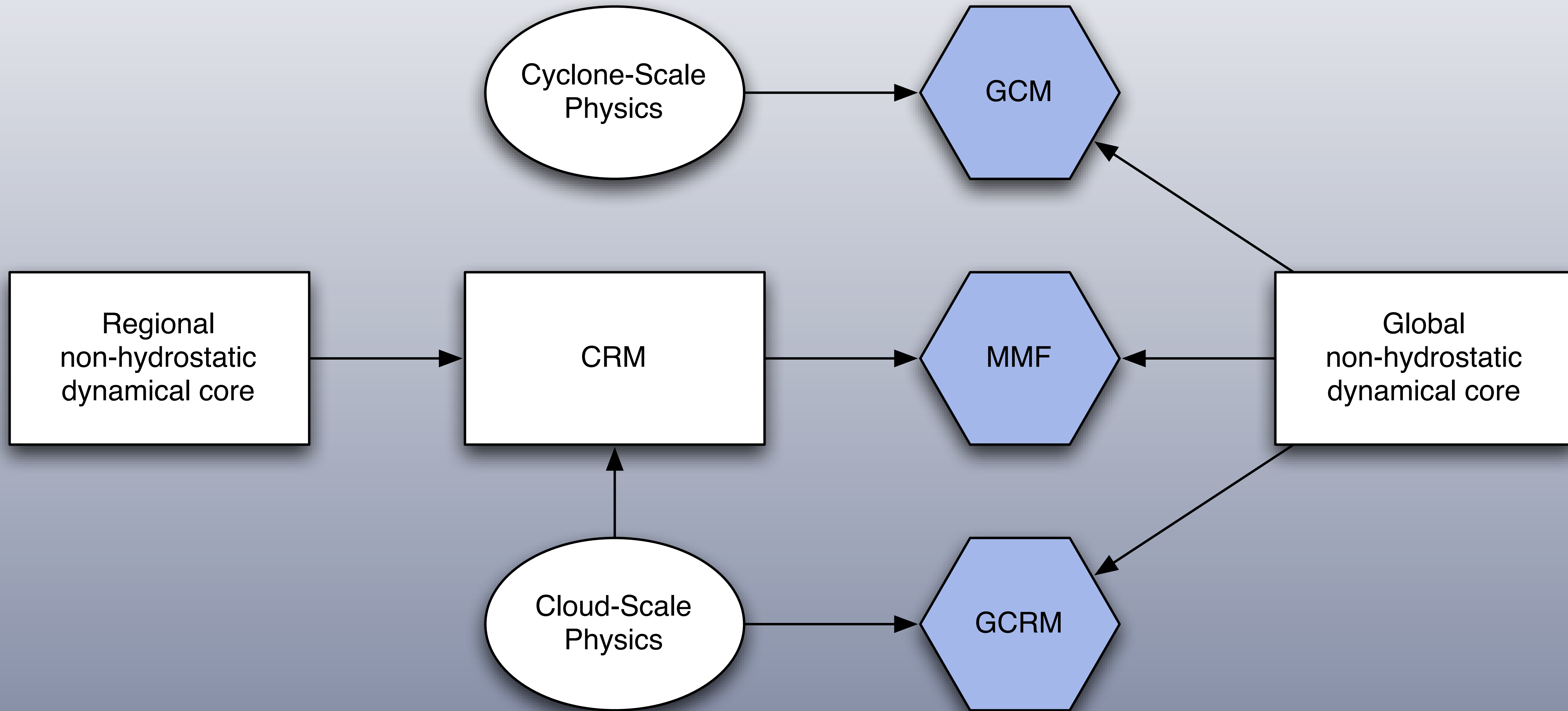
GCRM Status

- We have two working non-hydrostatic geodesic dynamical cores, both with unique designs.
- Off-the-shelf “local” physics is being added to the models now.

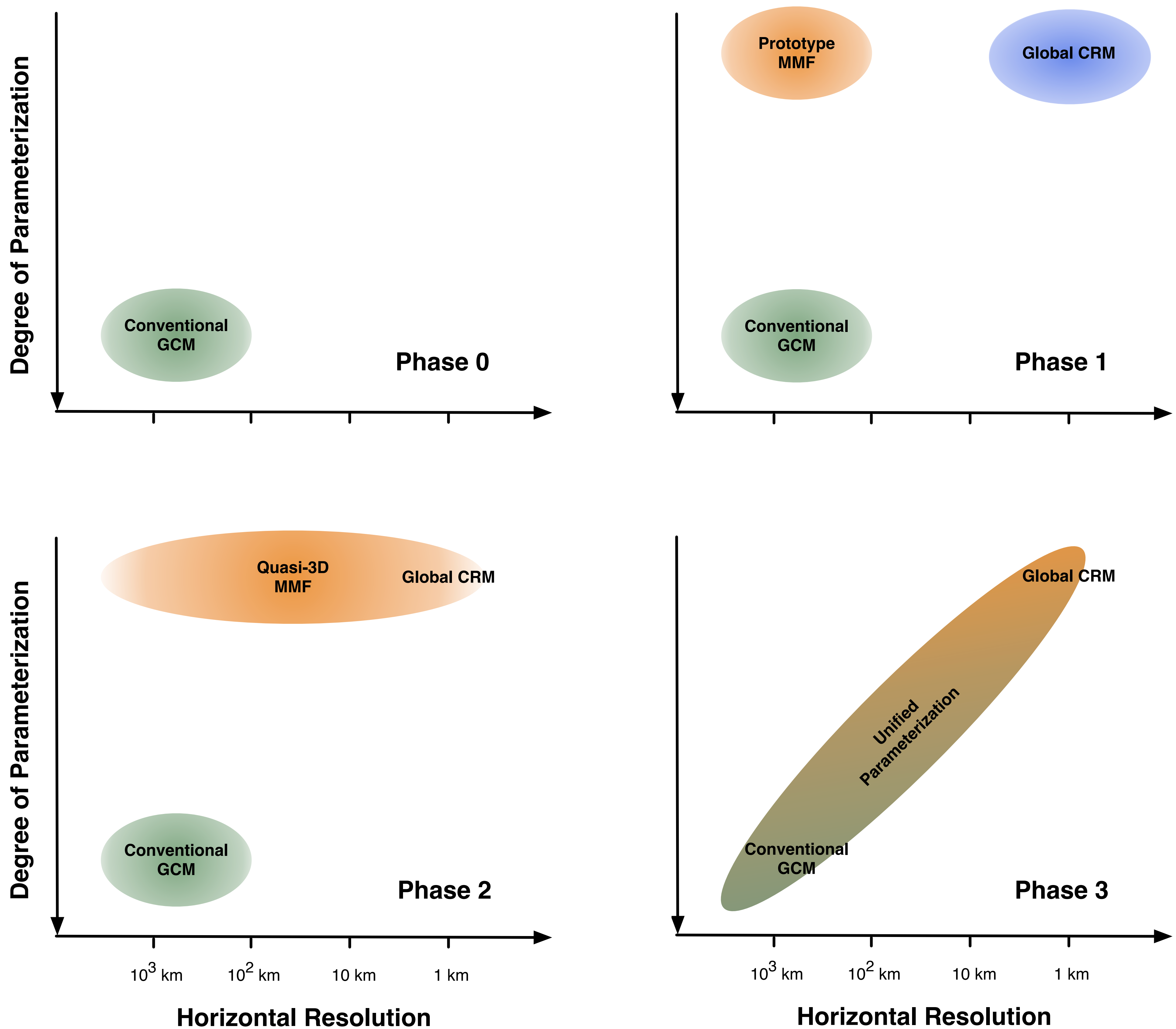
Scaling tests on Jaguar

Time (s)		Number of cores			
		5120	10240	20480	40960
Grid resolution	41,943,042 **(11)** (3.909 km)	8.652	4.535	3.071	2.377
	167,772,162 **(12)** (1.955 km)	35.567	18.071	8.885	5.646
	671,088,642 **(13)** (0.977 km)	Insufficient memory	79.85	36.137	18.903

Landscape

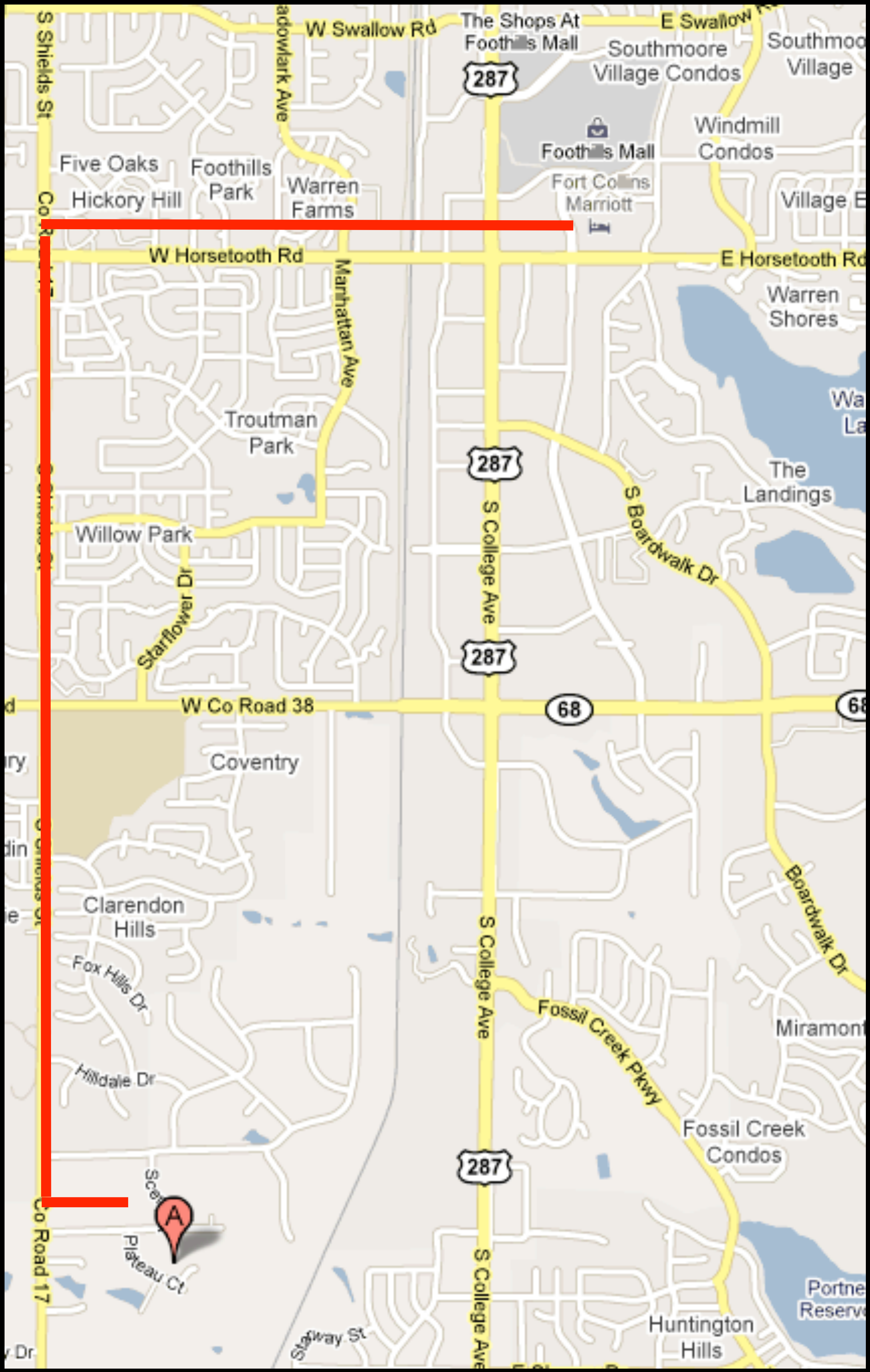

Cyclone-Scale Physics
GCM
Regional non-hydrostatic dynamical core
CRM
MMF
Global non-hydrostatic dynamical core
Cloud-Scale Physics
GCRM

The next challenge



Concluding Remarks

- It has taken about 50 years to reach our current modeling capability.
- Computers and GCMs co-evolve. Current technology trends are pushing models towards higher resolution.
- Explicit representation of deep convection over the entire globe is now possible, and will revolutionize the field.
- A current challenge is to formulate a parameterization that can be used with a wide range of horizontal resolutions.



Horsetooth to Shields

Shields to Scenic Drive

Scenic to Plateau Ct.

Second house on left

Park on street

Follow walk from street to house

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